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DISCUSSION OF A KINETIC THEORY OF GRAVITATION, II, AND SOME NEW EXPERIMENTS IN GRAVITATION.

(Plates V. and VI.)

By CHARLES F. BRUSH.

(*Read April 22, 1921.*)

At the Minneapolis meeting of the American Association for the Advancement of Science I had the honor to outline "A Kinetic Theory of Gravitation,"[1] which is in substance briefly as follows:

The ether is assumed to be endowed with vast intrinsic kinetic energy in wave form of some sort capable of motive action on particles, atoms or molecules of matter, and propagated in every conceivable direction so that the wave energy is isotropic. The waves are of such frequency, or otherwise of such character, that they pass through all bodies without obstruction other than that concerned in gravitation. Distribution of the ether's energy is uniform throughout the universe except as modified by the presence of matter.

Atoms or particles are imagined to be continually buffeted in all directions by the ether waves like particles of a precipitate suspended in turbulent water.

Each particle or atom of matter is regarded as a center of activity due to its energy of translation initially derived from the ether. There is continual absorption and restitution of the ether's energy, normally equal in amount; but the ether is permanently robbed of as much of its energy as is represented by the mean kinetic energy of the particle or atom. The particle or atom thus has a field of influence extending in all directions, or casts a spherical energy shadow, so to speak, the depth or density of the shadow varying with the inverse square of distance. The energy shadow of a body of matter is regarded as the sum of the shadows of its

[1] *Science,* March 10, 1911; *Nature,* March 23, 1911.

constituent parts. The energy shadows of two gravitating bodies interblend, so that the energy density between them is less than elsewhere, and they are pushed toward each other by the superior energy density, or wave pressure, on the sides turned away from each other.

At the April meeting of the American Philosophical Society in 1914[2] I presented a discussion of above theory which I commend to the attention of those interested in the general subject of gravitation—the greatest of all outstanding physical problems.

While it is easy to picture the formation of the initial energy shadow of a *single* body of matter, I have always found it difficult to account for the maintenance of such a shadow. But when we consider two or more bodies (and there can be no manifestation of gravitation without involving two or more bodies), there is no trouble in picturing the interblending energy shadows between them, and this is the essence of the theory under discussion.

That the ether really *is* endowed with vast intrinsic energy in some form or forms is the belief of many eminent physicists, and it seems to me highly probable that *all* energy has its source and destination in the ether; that is to say, that energy in all the various forms in which we observe it comes in some way from the ether and is energy *of* the ether.

In this connection I beg to propose the hypothesis that the ether is abstract energy—energy pure and simple, quite apart from anything else. If the quantum theory of energy is tenable, then we may perhaps regard the ether as a vast atmosphere of energy quanta in violent agitation possibly somewhat like the molecules of a hot gas, though almost infinitely finer grained.

In support of my contention that ethereal energy is the cause and essence of gravitation, I wish to emphasize particularly, what seems to me an obvious fact, that the energy acquired by a falling body comes from the ether, and is restored to the ether when the body undergoes negative gravitational acceleration. (See Discussion above referred to.)

For many years I have sought for some experimental method of attacking the gravitation problem, but without success until a few

[2] *Proc. Amer. Phil. Soc.*, Vol. LIII., No. 213, Jan.–May, 1914.

months ago. Study of the nature of gravitation is beset with unusual difficulties, because gravitation is ever with us and about us; it is the one universal phenomenon, and we can not escape from its influence—can not obtain any outside point of view.

In this connection I have endeavored to study the nature of a magnetic field in the hope of finding something common to it and gravitation; because we can largely localize a magnetic field and study it. Have long regarded a magnetic field not as a static affair, but alive with pulsating ethereal energy possibly akin to that of a gravitation field.

This view finally led to the thought that the very minute negative permeability of many substances, known as diamagnetism, may also offer some appreciable resistance or obstacle to the gravitational energy flux through such substances, and thus affect their gravitation field.

But what will be the nature of such modification, if any? It seems highly improbable that there can be any absorption of ethereal energy by a diamagnetic substance, because this would almost certainly generate heat in it—it would normally be warmer than its surroundings. I have carefully tested bismuth for this effect and found no generation of heat. But there may be a very slight reflection of the ethereal wave energy from each atom or ultimate particle of a diamagnetic substance, which may perhaps be regarded as a *scattering* effect, possibly analogous to the scattering of light by a faint opalescence in an otherwise transparent body. This I thought should weaken the gravitation field between a diamagnetic substance and a small neighboring body, whereby the attraction between them would be less than between the same neighboring body and a non-diamagnetic or less diamagnetic substance of the same mass as the first diamagnetic substance.

I realize that there may be no real foundation for the speculations detailed above, though I now have much experimental evidence which appears to support them; but, if for no other reason, they are important because they prompted the following experiments and brought to light their surprising results.

The first experiments were planned to detect, if possible, a difference between the gravitation field of a comparatively large mass of the metal bismuth, which is the most diamagnetic substance known, and the gravitation field of a similar mass of lead and of zinc, which are very much less diamagnetic than bismuth, and also of tin which is slightly paramagnetic. To this end it was proposed to measure the minute gravitational attraction between each of the above masses and a very much smaller nearby mass of some metal, the same small attracted mass to be used in all cases. In such a scheme the large masses would do nearly all the attracting, and their several gravitational pulls *per unit* of *mass* would be comparable.

To carry out this scheme Professor Dayton C. Miller very kindly provided, from his large collection of physical apparatus, a beautiful instrument designed for class-room demonstration of gravitational attraction between two small silver balls and two large lead spheres in the usual manner of such apparatus. It is a modification of the apparatus designed and used by Professor C. V. Boys for determining the gravitation constant and the mean density of the earth. Each small silver ball weighs three fourths of a gramme, and the pair are mounted at the ends of a horizontal small straight metal rod, with their centers 3.6 cm. apart. Rising from the center of this connecting rod is a small vertical rod carrying, at a distance of 6 cm. above the silver balls, the usual small mirror for scale reading, set at an angle of 45° with the ball-carrying rod. These parts constitute the oscillating system, and are suspended by a long quartz filament in a brass tube, the balls only projecting below the tube into a narrow glass-walled chamber, made shallow in order to minimize convection currents inside. Means are provided for leveling the whole apparatus, for orienting the free-hanging system and for clamping the balls when not in use. The apparatus is permanently grounded through one of its leveling screws.

The large lead spheres and their carriages were discarded and replaced by a light reversible wooden carriage.

The photograph, Plate V., shows the apparatus as set up in my basement laboratory. The delicate part first described is mounted on a heavy marble slab firmly bracketed in the angle of two twenty-inch brick walls. These are inside walls, and hence not liable to sudden

temperature changes due to outside weather conditions. The whole lay-out is thirty feet from the nearest window, and the temperature of the laboratory is very uniform and steady. The room selected is an inside one and contains no heating apparatus. The floor is thick concrete. The reading telescope shown in front and the carriage referred to are mounted on a massive table with thick marble top, nowhere touching the bracketed slab or the walls to which it is attached. The illuminated millimeter scale is two meters to the right of the oscillating system and does not show in the picture.

It will be noted that the tall brass tube containing the quartz filament is loaded at the top with a hollow cone of metal. This is found to increase the stability of the suspension apparatus very greatly by so lengthening the period of free vibration of the upper end of the tube that it can not respond to vibrations of the building due to street traffic or other causes. Although the nearest street is 300 feet away, traffic vibrations often can be felt.

The whole apparatus is protected from radiant heat of the scale lamp, and one other more distant lamp used to light the room, also from the heat and breath of the observer, by screens of cellular paper (not shown). All air drafts in the room are avoided as carefully as possible. The rheostat on the wall in the upper part of the picture has nothing to do with the apparatus, and never is used during observations.

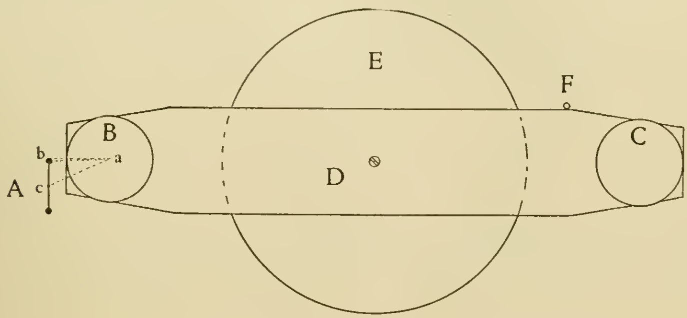

FIG. 1.

Fig. 1 is a plan diagram of the essential parts. The suspended silver balls are seen at *A*. *B* and *C* are cylinders of different metals, such as bismuth and zinc for instance, whose attractions for the nearer silver ball are to be compared. The cylinders are carried on the ends of a thin strip of wood *D*, which is pivoted at its center to, and supported by, a thick disc of cast iron *E* whose upper face is dressed flat and leveled. The height of *E* is such that a horizontal plane midway between the upper and lower ends of cylinders *B* and *C* is in the center plane of the balls *A*. The carriage *D* is covered with tin-foil kept in metallic contact with *E* by a brass-wire spring. *E* is permanently grounded; thus *B* and *C* are always grounded.

The cylinders *B* and *C* are very carefully so placed on the carrier *D* that when the latter is revolved 180° and brought against a removable stop-pin *F*, *C* will occupy exactly the same position in respect to the balls *A* as did *B* before the reversal.

All the metals experimented with are in the form of cylinders of the same size, 4.9 cm. high and 6.1 cm. diameter. When in position, the surface of a cylinder is 1.3 cm. from the center of the nearer silver ball.

The zinc cylinder weighs 1.014 kg., and the other cylinders weigh more or less than this according to their several specific gravities.

The zinc cylinder attracts the nearer silver ball with a force of about one three hundred thousandth part of a dyne, and as the oscillating system is very sensitive, having a free period of seven and a half minutes, the excess of this attraction over that for the more distant ball gives a scale deflection of about 4.2 cm., which is ample for observation, because deflections are easily read to 0.1 mm. As the mirror doubles the real deflection, the latter is 2.1 cm. at a distance of 2 meters. Hence the silver ball moves about 0.2 mm. toward the attracting cylinder, where the attraction is about 1 per cent. greater. This change in attracting force is approximately corrected by so locating the cylinder *B* that the angle *a b c* is slightly obtuse at the start, and becoming more so as the ball advances causes the attractive effort to be less effective. Hence the deflection as read by the telescope may be taken as a closely approximate measure of the attraction of the cylinder for the ball. Of course, the center of attraction in the cylinder does not lie in its axis, though near it. But this does not matter, because its location is the same in all the cylinders.

The attraction of B on the silver balls must draw the oscillating system out of plumb; but as this effect amounts to only about a millionth of a millimeter, it is entirely negligible.

Prior to using the apparatus the cylinders are swung into a position at right angles to that shown, all lights are extinguished except those to be used in making observations, and the room is closed against all draft. After two or three hours of repose, to equalize temperatures, one of the cylinders is moved into operative position a minute or two only, to start a definite movement of the oscillating balls. Then the diminishing oscillation limits are read 6 or 8 times to establish the zero point. Next, one of the cylinders is moved into operative position and left there until 6 or 8 oscillation limits have been read; then the cylinders are exchanged by reversing the carrier, and 6 or 8 more deflection readings are made. Twice again the cylinders are exchanged and similar readings taken, so that two sets of readings are had for each cylinder. Usually they agree very well indeed, and their mean is taken as the true value. Finally, both cylinders are swung out of position as at first, and another set of readings taken to redetermine the zero point.

Although such a series of readings occupies about four hours, the zero drift rarely exceeds two scale divisions (2 mm.) and, assumed to have been progressive, is apportioned among the several sets of readings.

In the above manner many comparisons have been made of lead and bismuth; lead and zinc; bismuth and tin; bismuth and zinc; silver and zinc; and lastly of aluminum and bismuth and aluminum and zinc.

The interlacing observations support each other very satisfactorily.

In every case the observed deflection is divided by the weight of metal causing it, so as to reduce all to a common standard of attraction per kilogram.

Table I embodies the results thus far obtained, taking zinc for a standard and calling its attraction per kg. 100.

TABLE I.

Aluminum	130
Zinc	100
Tin	100
Lead	93
Silver	80
Bismuth	72

Each of the above values is the nearest whole number to the mean of many observations except in the case of silver, which is based on one set only.

Occasionally, though not often, deflections were observed which were considerably less than usual for the metal used, and sometimes unequally less for the two metals being compared, thus showing less or more contrast between them—usually less. But in no case was the contrast even nearly obliterated, nor its sign changed. The cause or causes of these occasional irregularities have not yet been ascertained, but are diligently sought. In view of them, however, the values given in the table must be regarded as fairly good first approximation only.

Pure iron was tried because, magnetically, it is the antithesis of bismuth. But while it caused deflections neither very large nor very small, they were quite irregular, doubtless due to local disturbance of the earth's magnetic field. The slight residual magnetism after the iron cylinder was subsequently magnetized horizontally caused it to give widely different deflections when differently oriented. But from certain pendulum experiments next to be described it is thought that iron should have a place in Table I, somewhat nearer zinc than bismuth, say about 87.

The zinc and tin used in these experiments are of commercial purity only; the bismuth, silver and lead are almost chemically pure, and the aluminum contains traces of silicon and iron.

It is interesting to note that bismuth exhibits much the smallest attraction per unit of weight, as was hopefully predicted; and although this may not be due to its exceptional diamagnetic qualities, the possibility that it is so due promises a fruitful field for future exploration. If further experimentation seems to warrant it, I shall, in a future paper, endeavor to expand the idea that diamagnetism is not simply a manifestation of negative magnetism (and this view is supported by the fact that diamagnetism is not affected by varying strength of magnetic field), but is an inherent attribute, in varying degree, of many kinds of matter, often more or less masked by paramagnetic qualities.

It is also interesting to note the low atomic weight and small density of aluminum at one end of the scale of attractions, and bismuth with its very high atomic weight and large density at the other end.

It seems needless to say that the line of investigation indicated by the foregoing experiments is but barely begun. It is proposed to try many other metals, as well as alloys and chemical compounds, in the hope of finding some general law embracing all.

If such further experimentation confirms, in general, the findings already made, and I have yet found no reason to doubt that this will be the case, the scientific possibilities of the discovery are rather bewildering. It may mean, among many things, that we shall have to revise our notions of atomic weight values; that the second part of Newton's law of gravitation is not general in its application, and that if Professor Boys and others had used zinc or tin or bismuth for their large attracting spheres, instead of lead, their findings for the gravitation constant and mean density of the earth would have been materially different, though still erroneous.

As soon as the above-described experiments had proceeded far enough to afford reasonable assurance that the effects observed were not spurious, though very much larger than looked for, I planned and began work on some pendulum experiments in the hope of again showing that weight and mass are not related in so simple a manner as heretofore supposed.

Of course weight is only an accidental attribute of mass and varies enormously in different localities, as on the sun, the earth, the moon and in interstellar space; while mass remains constant everywhere. But relative weight has always been taken as a true measure of relative mass in the same locality. The foregoing experiments seem to refute this; hence the pendulum experiments were undertaken for proof or further refutation.

Undoubtedly the commonly accepted measure of mass, viz., its resistance to a definite accelerating force, positive or negative, is reliable and safe.

If, then, we have two pendulums of exactly the same real length, one with a zinc bob and the other with a bismuth bob, and find that their periods are not the same, we may reasonably infer that the accelerating force of gravity acts more strongly per unit of mass on the one having the shorter period than on the other. This is the principle, though not exactly the method, of the pendulum experiments next described.

It was realized from the start that the difference, if any exists, must be very small, and not easy to detect, because the earth's field is so enormously preponderating that it does virtually all the attracting; and the supposed differences in the extremely weak fields of the zinc and bismuth may be so nearly lost in the immensity of the earth's field as to be undetectable. Nevertheless, it was thought worth while to try the experiment in view of the importance of the subject.

The photograph, Plate VI., shows the pendulum apparatus as originally installed, together with driving clocks at the top, added later for long-continued observations.

A starting cradle, moving in guides on the low table just below the cylindrical zinc and bismuth bobs, serves to start the pendulums swinging exactly together in any desired amplitude. After pushing the bobs sufficiently to the left, the cradle is suddenly withdrawn to the right, leaving the bobs free. This device is entirely satisfactory in performance.

A horizontal thick plate of hardened steel is very firmly bolted to the lower flange of a heavy iron I beam imbedded in the masonry of the ceiling and walls of the room. The plate is dropped 6.5 cm. below the beam by cylindrical iron spacers through which the bolts pass and is carefully leveled. Near one edge of the upper face of the plate is a long shallow V grove of 90° angle, with a slightly rounded bottom carefully ground straight and polished after the plate was hardened.

From this plate hang two exactly similar pendulums of about

2.284 m. effective length and 15.2 cm. apart. Each pendulum rod, except for a few cm. at each end, is of mild steel, perfectly straight and 1.6 mm. diam. Both rods were cut from the same specimen, so as to have the same temperature coefficient. The upper 20 cm. of each rod is 0.4 cm. diam. round steel with fine screw thread and thumb nut on its upper part. The thumb nut has eight radial holes for a long brass pin, the whole adapted to effect very fine adjustment of pendulum length. The thumb-nut rests on the horizontal face of a 60° triangular "knife-edge" of hardened steel through which the rod passes. The upper part of the rod is slightly flattened on one side by grinding, and a thumb-screw in one end of the knife-edge block bears against the flattened side of the rod and clamps it firmly in the block after each length adjustment is made. The knife-edge, ground true and sharp, rests in the plate groove above described, while the rod passes downward through an opening in the side of the plate.

Each pendulum rod terminates at its lower end in a straight brass rod 13 cm. long and 0.4 cm. diam. A perfectly straight horizontal steel pin passes loosely through the brass rod near its lower end, and on this pin the cylindrical bob, or weight as I shall hereafter call it, rests.

Fig. 2 shows the upper and lower parts of one pendulum in detail, with the bismuth weight in place.

The brass rod at the lower end passes just freely through the weight, and accurately in its axis. A weight is easily removed from either pendulum by lowering it after the pin is withdrawn, and another weight may be substituted by reversing the procedure. While this is being done the pendulum rod is kept taut by another temporary, radially slotted, lead weight applied just above, and resting on the upper end of the brass rod. Thus the weights forming the bobs of the two pendulums may readily be exchanged without disturbing anything else.

The weights to be compared, bismuth and zinc in the first instance, were made very accurately the same in height, and with upper and lower ends as nearly plane and parallel as possible, by careful grinding on a perfectly flat surface.

It is essential that the centers of gravity of the weights be exactly the same distance above their supporting pins. To assure this, each weight was adjusted to have its center of gravity exactly midway between its upper and lower ends by the following procedure: The pendulums having been started swinging with a definite amplitude

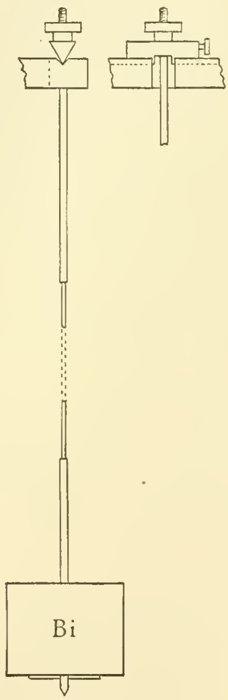

Fig. 2.

and brought to synchronism by length adjustment, one of the weights was turned over; this at first resulted in loss of synchronism at the same amplitude. Then, as indicated, the upper or lower cylindrical portion was slightly reduced in diameter by turning off or sandpapering in the lathe. Again the pendulums were synchronized, and again the same weight was turned over and synchronism tested. This process was repeated again and again with each weight until either could be turned over without affecting synchronism in the slightest observable degree. In making these adjustments very minute departure from synchronism could be detected in half an hour at the turning points of the swing. For certain reasons all tests were made with the same initial amplitude.

Instead of making the cylinders the same in diameter, they were made approximately the same in *weight*, about 1.377 kg., so that when they were exchanged the length of the pendulum rods would not be affected. Otherwise it would have been necessary to apply corrections for the elastic modulus of the rods and for their *weight* with every exchange. The latter correction would have been very important, but liable to error.

Finally, the zinc and bismuth pendulums were adjusted to synchronism as perfectly as possible in 40-minute runs with initial amplitude of 35 cm. As it turned out, the bismuth pendulum was then materially *longer* than the zinc one. It was the whole aim of the pendulum experiments to detect and measure this difference if it existed.

Next the weights were exchanged, so that, in effect, the bismuth pendulum was now the *shorter* one by *double* the former difference. On again starting the pendulums, at the former amplitude, loss of synchronism was easily observable in 2 minutes—the bismuth gaining. In 40 minutes the bismuth gain was very large. In the same and other forms this experiment was repeated many times, and always with the same unequivocal result.

Equality of air resistance was effected by attaching small paper projections to opposite sides of the bismuth normal to the line of swing, of such size as to produce air damping equal to that of the zinc as shown by equal time loss of amplitude.

It appears from this experiment that the earth's gravitation field, which is here the accelerating force, grips the bismuth more strongly per unit of mass than it grips the zinc per unit of mass; in other words, a given mass of bismuth appears to *weigh more* than the same mass of zinc. Apparently the length of a seconds pendulum depends on the material of which it is made.

The greater diameter of the zinc cylinder slightly lowers its center of oscillation, and this accounts for about 10 per cent. of the effect above described, as determined by elaborate experimentation which need not be detailed here, and which was verified by computation.

A pair of high-grade, weight-driven clock movements were next added to the apparatus, as shown in the upper part of Plate VI., and adapted to drive the pendulums continuously at an amplitude of 13 cm.

After synchronizing the zinc and bismuth pendulums at this amplitude, the zinc and bismuth weights were exchanged as heretofore described. Then they were started exactly together and allowed to run until they were again exactly together, the bismuth having thus gained two full beats. Half the elapsed time was taken as the value of *one* beat gain.

Again the pendulums were synchronized, the zinc weight now being on the pendulum formerly occupied by the bismuth weight; then the weights were exchanged as before, the pendulums started together, and allowed to run until the bismuth had gained two beats as formerly. This procedure was for the purpose of verifying the first finding and to expose any considerable difference there might be in the performance of the driving clocks. No such difference was found; yet for verification the same procedure was followed in the next experiments.

A cylinder of very pure iron was next prepared, of exactly the same height, and approximately the same weight as the zinc and bismuth cylinders, and adjusted for center of gravity with the same care.

The iron weight or cylinder was then compared with the zinc weight and with the bismuth weight, with the same care used in comparing the zinc and bismuth as above described. The iron gave results intermediate between those of zinc and bismuth, rather nearer the zinc.

Table II. shows the performance of the zinc-iron, the iron-bismuth and the zinc-bismuth combinations. The measurements of time required to gain one beat check and confirm each other remarkably well.

As the pendulums make about 2,388 oscillations per hour, the bismuth gains one beat, or oscillation, in about 17.432; but as before pointed out, the real zinc-bismuth effect is only half of this, say one part in 35.000. This *weight-mass difference* effect, though not large, appears fairly well established and is impressive.

TABLE II.

Zinc-Iron	15½ hrs.	Mean 17 hrs.
	18½ "	
Iron-Bismuth	13 hrs.	Mean 13 hrs.
	12½ "	
	13½ "	
Zinc-Bismuth	7 hrs. 20 min.	Mean 7.3 hrs.
	7 " 16 "	

Zinc — Iron — Bismuth

17 hrs. (Zinc to Iron) — 13 hrs. (Iron to Bismuth)

7.3 hrs. (Zinc to Bismuth)

Reciprocals:

$$\frac{1}{17} + \frac{1}{13} = \frac{1}{7.36}$$

Various further pendulum experiments are contemplated; and an apparatus adapted to compare the velocities of freely falling masses of zinc and bismuth, and perhaps even *measure* their difference, if any, has been designed.

In the foregoing pendulum experiments the only force involved for both weight and acceleration was gravity. In the following experiments the accelerating force of a flexed spring was substituted for that of gravity.

Everybody is familiar with the so-called "anniversary" clock, a slow motion, torsion-pendulum clock adapted to run at least a year without rewinding. One of these clock movements of the best quality was used, and its regular disc pendulum was replaced by the arrangement shown in Fig. 3.

a is a very narrow ribbon of tempered steel about 11 cm. long, from which depends the brass member *b*. Rigidly clamped into the lower end of *b* is the horizontal brass rod *c*, carrying at its ends two bismuth cylinders *Bi*. *e e* are brass sleeves of equal length, just loosely fitting the rod *c*, to aid in the first rough adjustment of the cylinders.

The bismuth cylinders, and a similar pair of zinc cylinders, one of which is shown at the upper left, are all accurately cylindrical,